On the use of mutations to account for diversity in a multi-trait model of phytoplankton community

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SPEAD

Simulating Plankton Evolution with Adaptive Dynamics (SPEAD)

Objectives:

- Develop a marine ecosystem model that includes the adaptive evolution of phytoplanktonic organisms …

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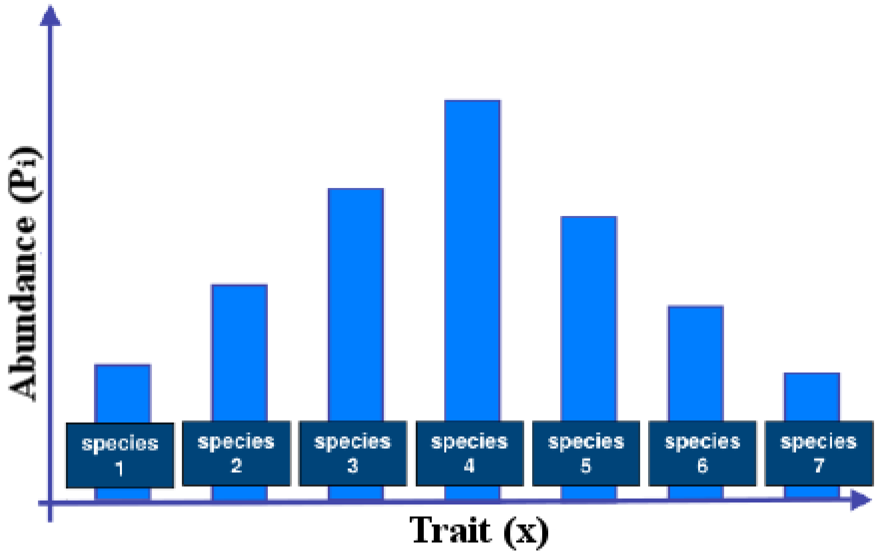
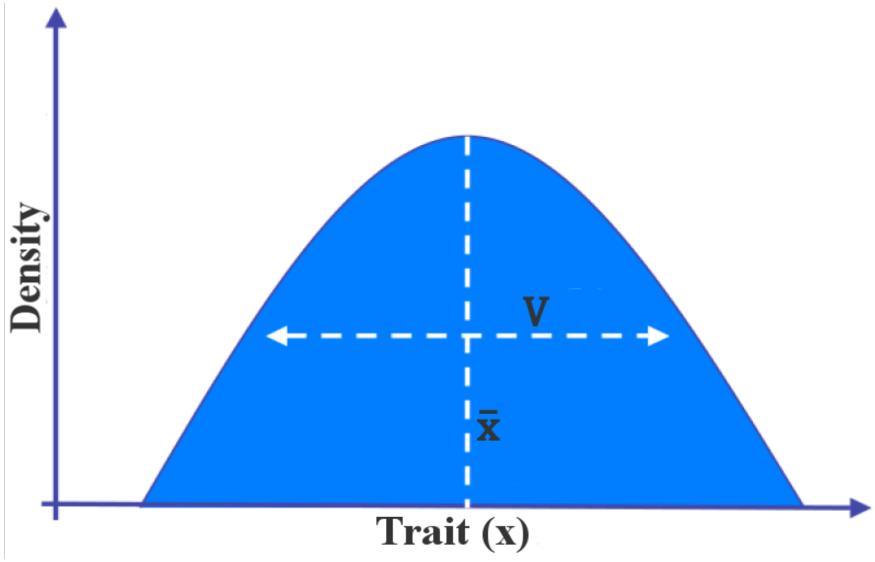
- … in order to better predict the response of marine ecosystems to climate change scenarios

Trait-based models

Traits are plankton characteristics affecting competition (size, optimal temperature, optimal irradiance, resistance to predation …)





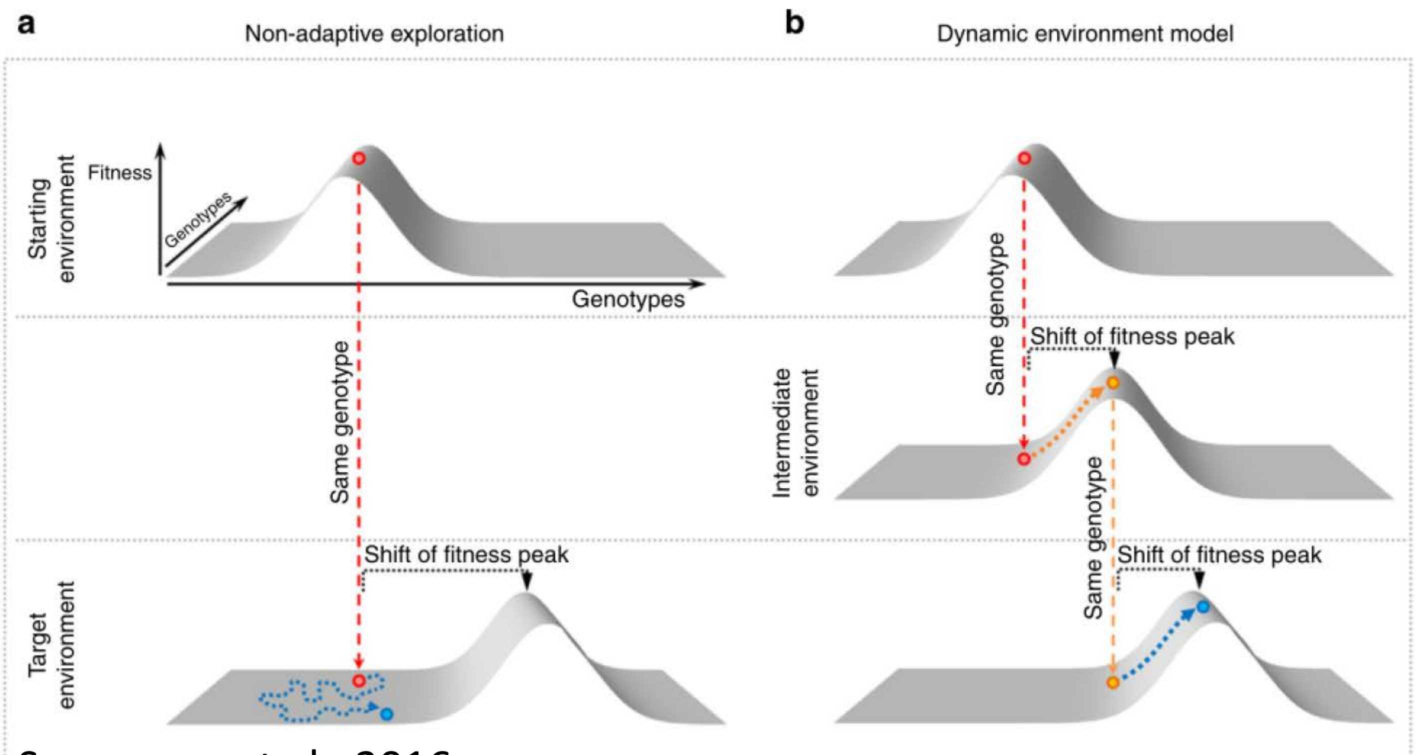
Multi-species model:
$P_1, P_2 \ldots P_n$

Aggregated model:
$P_{tot}, \bar{x}, V$

Adaptive dynamics

Mean trait moves to the value of highest fitness

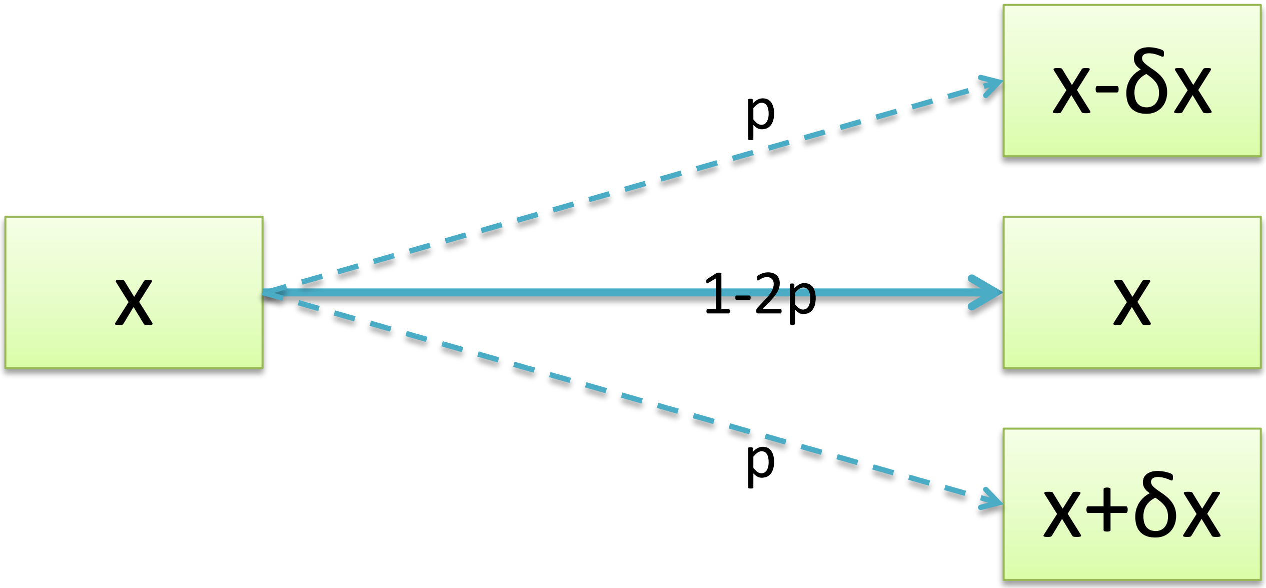
➢ Requires biodiversity



Szappanos et al., 2016

Trait diffusion (Merico et al., 2014)

The traits of offsprings can diverge from the traits of their parents, with a probability p. $p = \frac{\nu}{(\delta x)^2}$ where ν is a diffusivity parameter.

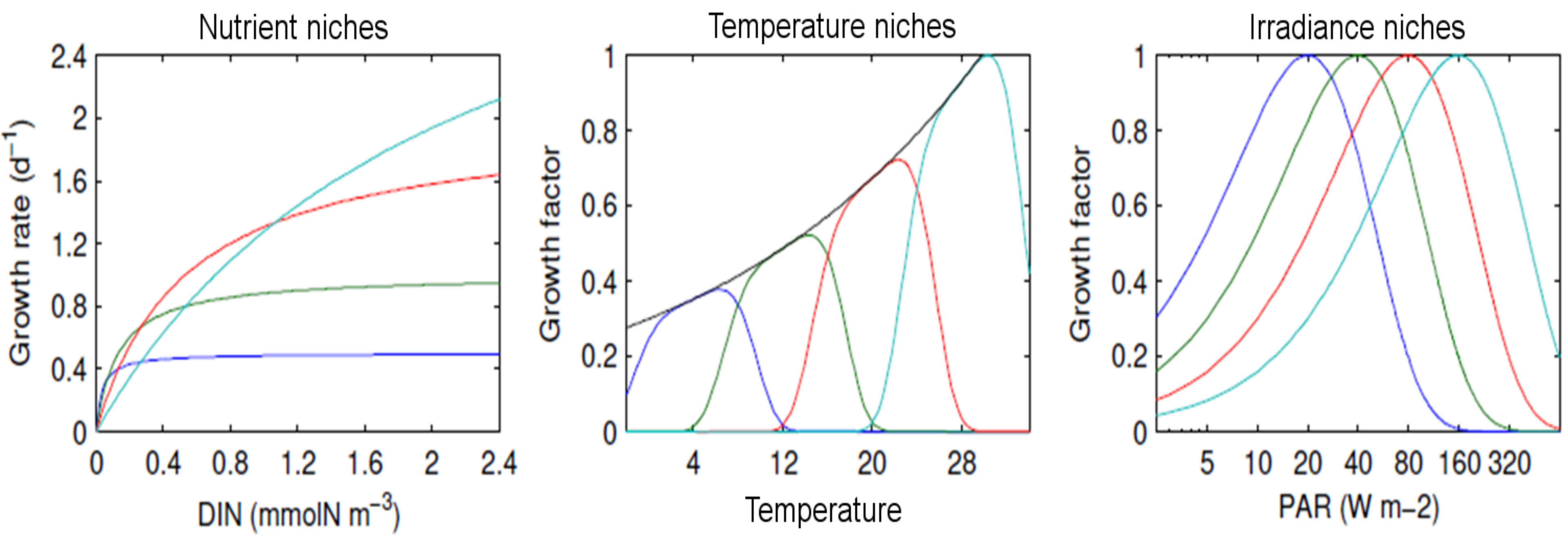


Represent all random and heritable mutations

Traits and trade-offs

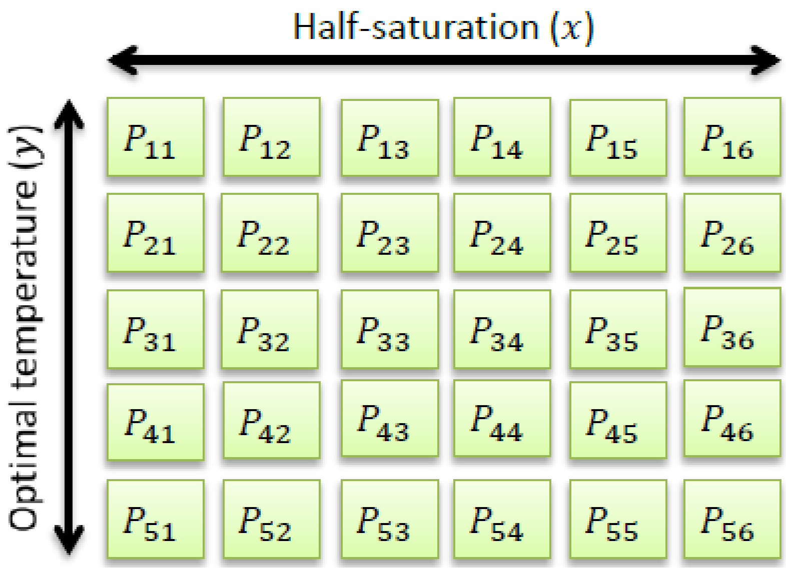
3 traits in the DARWIN model, 2 already included

- ✓ Affinity for Dissolved Inorganic Nitrogen, trade-off with maximum growth rate
- ✓ Optimum temperature (T_{opt})
- ➢ Optimum irradiance (I_{opt}) (yet to be included)



Multi-species (discrete) model

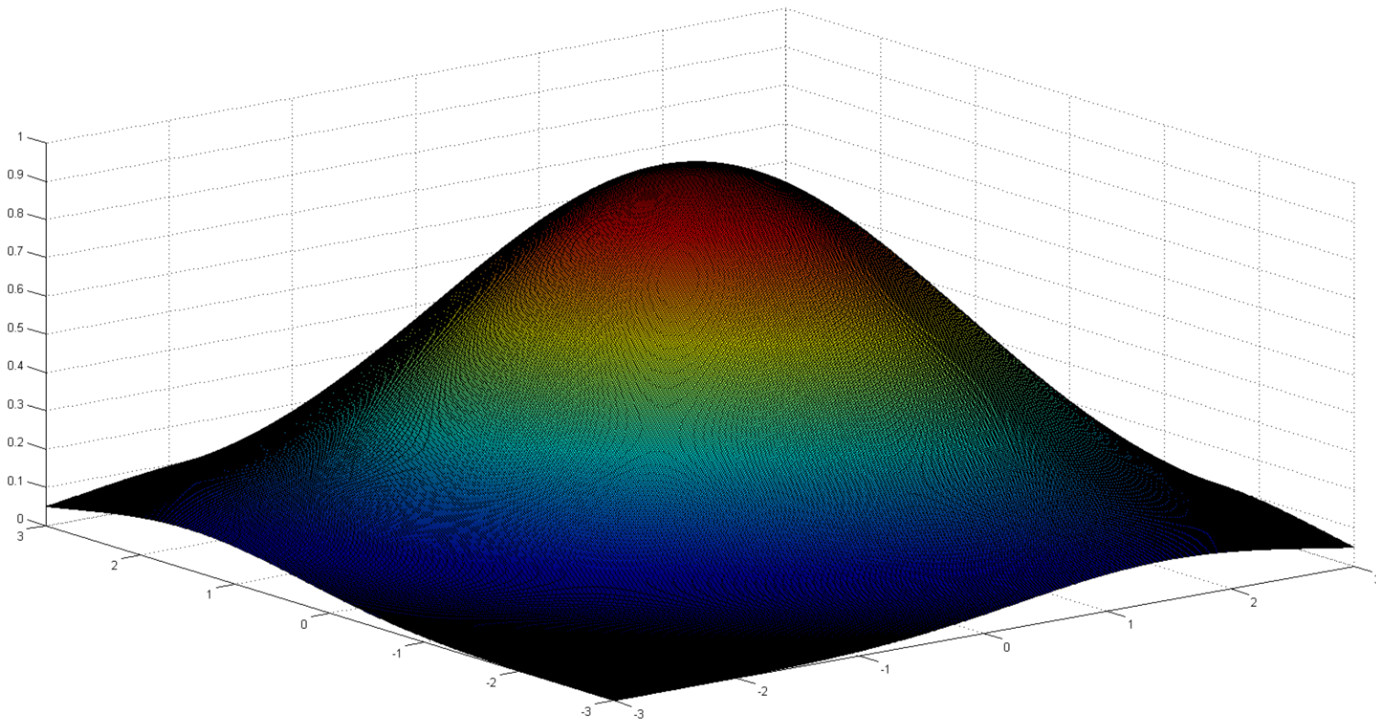
$N_x * N_y$ species with N_x values of x and N_y values of y



$N_x N_y$ differential equations → Computationally expensive

Aggregated (continuous) model

Bivariate normal distribution is assumed.



6 moments: P, $\bar{x}$, $\bar{y}$, V_x, V_y and C_{xy}

3 diagnostic variables: $\sigma_x = \sqrt{V_x}$, $\sigma_y = \sqrt{V_y}$ and $R_{xy} = \frac{C_{xy}}{\sigma_x \sigma_y}$

Aggregated (continuous) model

Differential equations derived using the method of Norberg et al. (2001)

The net growth rate (a) and the reproduction rate (r) are Taylor-expanded to the order 2 around the mean trait values ($\bar{x}$ and $\bar{y}$):

$$a(x,y) = a(\bar{x},\bar{y}) + \frac{\partial a}{\partial x}(x-\bar{x}) + \frac{\partial a}{\partial y}(y-\bar{y}) + \frac{1}{2}\frac{\partial^2 a}{\partial x^2}(x-\bar{x})^2 + \frac{1}{2}\frac{\partial^2 a}{\partial y^2}(y-\bar{y})^2 + \frac{\partial^2 a}{\partial x \partial y}(x-\bar{x})(y-\bar{y})$$

Equations of P, $\bar{x}$ and $\bar{y}$ follow directly. They depend on a, its derivatives and the moments of the trait distribution (P, $\bar{x}$, $\bar{y}$, V_x, V_y and C_{xy})

The equations on V_x, V_y and C_{xy} depend on moments of higher order (3 and 4). We make a closure by assuming a normal distribution.

Aggregated (continuous) model

$$\frac{dP}{dt} = P\left[a + \frac{1}{2}V_x a_{xx} + C_{xy}a_{xy} + \frac{1}{2}V_y a_{yy}\right]$$

$$\frac{d\bar{x}}{dt} = V_x a_x + C_{xy}a_y$$

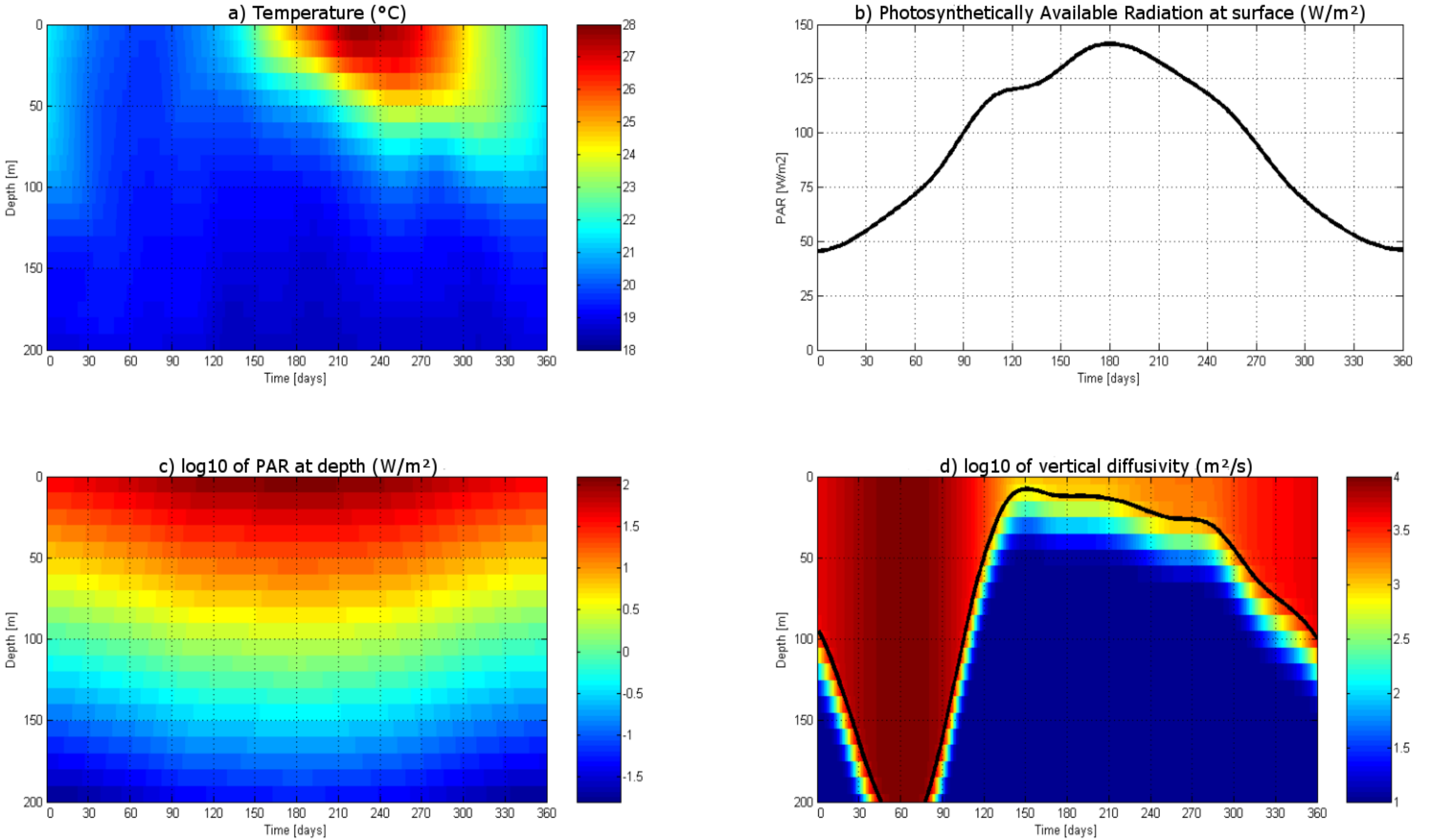
$$\frac{d\bar{y}}{dt} = C_{xy}a_x + V_y a_y$$

$$\frac{dV_x}{dt} = V_x^2 a_{xx} + 2V_x C_{xy}a_{xy} + C_{xy}^2 a_{yy} + 2\nu_x\left(r + \frac{1}{2}V_x r_{xx} + C_{xy}r_{xy} + \frac{1}{2}V_y r_{yy}\right)$$

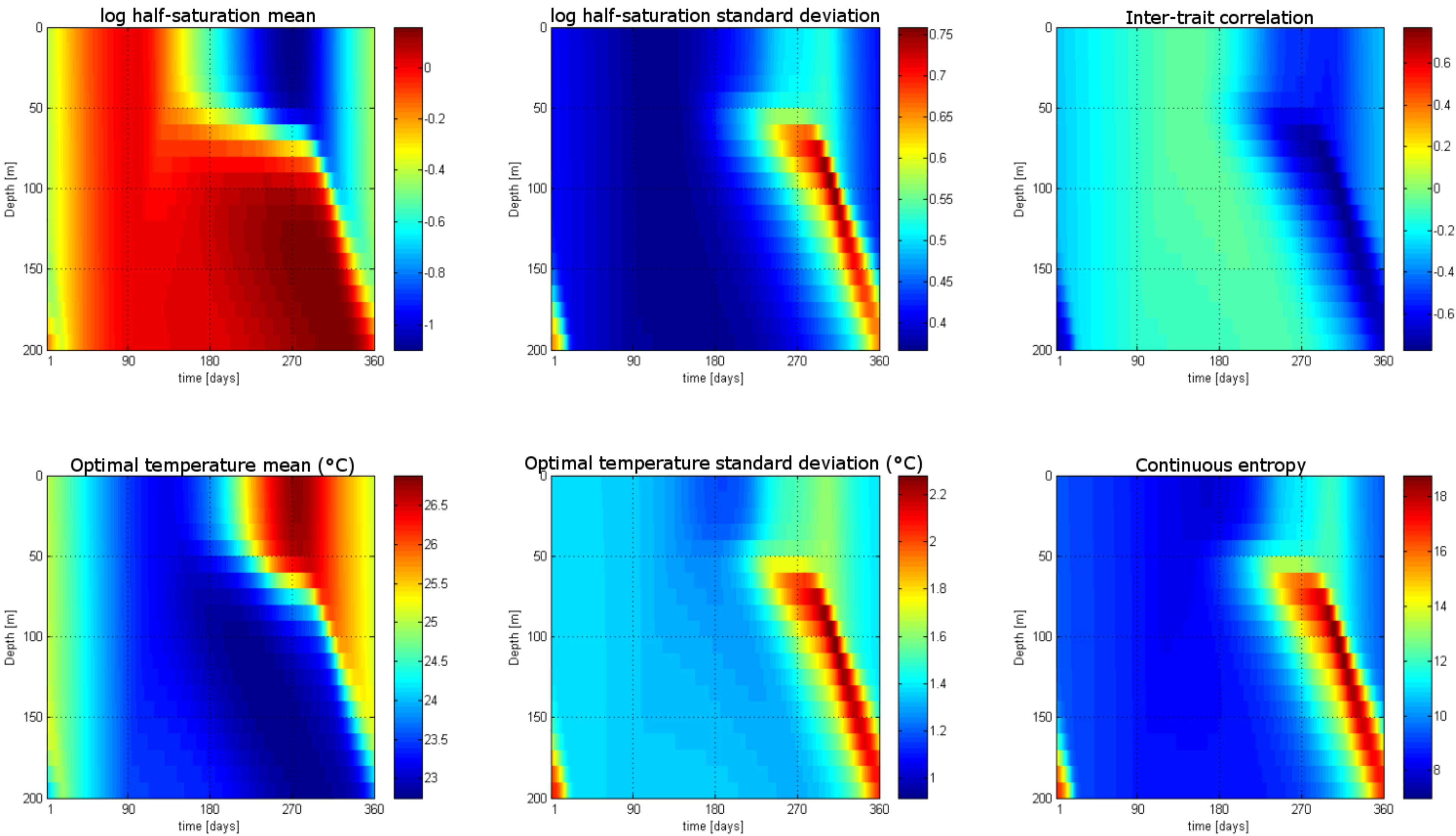
$$\frac{dV_y}{dt} = C_{xy}^2 a_{xx} + 2V_y C_{xy}a_{xy} + V_y^2 a_{yy} + 2\nu_y\left(r + \frac{1}{2}V_x r_{xx} + C_{xy}r_{xy} + \frac{1}{2}V_y r_{yy}\right)$$

$$\frac{dC_{xy}}{dt} = V_x C_{xy}a_{xx} + \left(V_x V_y + C_{xy}^2\right)a_{xy} + C_{xy}V_y a_{yy}$$

Forcings (from Sargasso Sea)



Continuous model outputs
($\nu_x = 0.002$ and $\nu_y = 0.018$)



Simulating Plankton Evolution with Adaptive Dynamics in a global ocean model (SPEAD)

- ✓ Develop an aggregated phytoplankton model with two traits
- ➢ Add optimal irradiance
- ➢ Couple with a circulation model (MITGCM) and simulate future changes in phytoplankton communities at a global scale (invasion vs adaptation)